

AN ECONOMICAL APPROACH TO SPACE POWER SYSTEMS

Fred Teren
NASA Lewis Research Center

A continuing concern of NASA is the high cost of its future space programs and, in particular, the cost of power and energy in support of space programs projected for the mid-1980's and beyond. Figure 1 illustrates projected energy demand for all NASA, DOD and Civil missions for the time span 1981 to 1995. It can be seen that the projected energy demand increases by about a factor of ten between 1981 and 1990. Typical energy costs have ranged from about \$300 to about \$2000 per kW-hr, with an average of about \$800/kW-hr for long-duration missions. At these levels, the cost of the required energy would be several billion dollars per year by about 1985 and might constrain the numbers and types of programs NASA will be able to carry out. Thus, it is important that NASA find ways to reduce the cost of space power systems. One way to accomplish this is to start with the traditional space-qualified systems approach and look for ways to reduce costs through modifications in procedures and changes in components. Non-recurring costs can be reduced by elimination of custom and unique designs for each mission and by volume buys to take advantage of mass production techniques. Also, unnecessary documents and specifications can be eliminated, and ways can be found to simplify the component parts. This approach is being pursued extensively in the NASA space power systems program.

The advent of the Space Transportation System (i.e. Space Shuttle) will affect the cost of space power systems in several ways. The most obvious effect will be a substantial reduction in the cost of transporting systems from Earth to low Earth orbit (LEO). A less obvious but potentially very important effect is that a new approach to accomplishing mission reliability is made possible. Historically, payload costs have typically been driven by requirements to assure that highly complex, advanced technology, irretrievable, weight-critical, and schedule-critical vehicles and spacecraft performed to full requirements on their first and only flight.

In order to establish that these systems have a high probability of performing for the mission duration, reliability requirements were introduced at the onset of the program and integrated into nearly every aspect of the development. They include such practices as conservative designs, redundancies, use of high reliability components, clean room facilities,

established fabrication techniques, quality control, inspections comprehensive testing, etc.

With the introduction of Shuttle it is possible to either service space systems in orbit, replace modules in space, or return faulty units to Earth for repair. Failure of a component or system in space need not imply mission failure. Thus, mission reliability can be achieved through a combination of component reliability, maintenance and servicing. This is what we refer to as the commercial approach to reliability. There are, of course, many reliable low cost commercial systems operating today which give dependable performance because they can be serviced. These systems, which were not designed for space application, include aircraft, automobiles, appliances, radios, television and large power generating equipment. With Shuttle making space servicing practicable, it is of interest to study the possible application of a low cost commercial approach to the design and fabrication of reliable space systems.

Inherently related to the use of a commercial approach is the use of commercial components (i.e. components used in terrestrial and/or aircraft equipment). Relative to space-qualified components, commercial components typically are produced in larger numbers and at lower cost but may be less reliable. Thus, the use of commercial practices and components represents a tradeoff between cost, reliability, and servicing, in which low cost is emphasized and reliability is achieved through servicing and maintenance.

The program objectives are therefore to demonstrate the applicability of a commercial approach and commercial components to the development of a low cost photovoltaic space power system. Once this has been achieved, the knowledge gained and procedures established can be applied to other space systems as well.

Before undertaking a substantial effort to identify and apply commercial practices to the development of space power systems, the potential for substantial cost reduction should be established first. In order to do this, mission and system requirements must first be specified, so that a possible power system and its components may be identified. The power system's proposed mission is a circular 200-nautical-mile-altitude Earth orbit having inclination of 28 degrees. The system must supply 2 kilowatts of electrical power continuously to the load and is specified to consist of a solar array power source and batteries for energy storage. Excess energy from the array is stored during periods of sunlight and transmitted from storage to the load during solar occultation.

A comparison of costs of space-qualified and commercially

available equipment is shown in table I for the principal categories of a space power system which is designed to meet the above specified requirements. A 5-kW solar array is required to deliver 2 kW average power to the load. The space-qualified solar array blanket is assumed to cost 1.5 million dollars, or \$300/watt. Approximately one kW-hr of energy storage is required, and NiCd batteries are used for this purpose. Power processing includes a battery charger and bus regulator, and mechanical systems include a solar array drive and deployment mechanism. It is assumed that the commercial system will utilize industrial type components such as terrestrial solar arrays and avionics batteries and power converters. It can be seen that over half the cost of the space-qualified system is the cost of the solar array. On the other hand, a cost of \$30/watt is typical for a terrestrial array. Substantial cost savings are also possible if commercial equipment is used instead of space-qualified equipment in the other categories.

Overall, nearly an order of magnitude cost reduction is estimated to be possible - \$390,000 for the commercial system vs. \$2,650,000 for the space-qualified system. It is recognized, however, that the quoted costs for the commercial equipment are based on the use of the system in a terrestrial environment. Some modifications would surely be required if this equipment were to be used in the space environment, and these modifications would inevitably increase cost. However, these cost increases are expected to be small compared to the potential cost saving of over two million dollars. On the basis of these preliminary cost estimates, further pursuit of the commercial approach is justified.

Our approach to the development of an economical approach to space power systems is to conduct two programs, which we call ECOP (Economical Orbital Power) and SPEX (Space Power Experiment). The objective of ECOP is to demonstrate the applicability of a commercial approach to the development of a low cost photovoltaic space power system. The objective of SPEX is to demonstrate the application of industrial hardware for space power systems.

The ECOP program starts with studies and leads eventually to the design, fabrication and testing of a 2-kW space power system. The studies will define and compare commercial and space-qualified approaches to the design, fabrication and testing of a photovoltaic space power system and estimate the cost which would result for each approach. The specific power system type to be considered is a photovoltaic system, with rechargeable batteries for energy storage. Batteries, rather than fuel cells, are specified for energy storage because of the availability of both space-qualified and industrial

types. The system is to operate in a low Earth orbit and is to provide 2 kW of average power to the load. A contract has recently been initiated with Solarex to study the commercial approach to space power system development. A second contract is anticipated, to conceptually design and estimate the cost of a space power system using the traditional space-qualified approach. The Solarex contract will examine the commercial approach in detail, including the approach to design, fabrication, documentation and R&QA. Considered in the study will be costs, manpower, methods, practices and procedures involved for a complete cycle of a new product from conceptual design to a finished fabricated product. These studies will estimate the cost of space power systems developed through the use of commercial and space-qualified approaches. This will establish with more assurance the potential for cost reduction of space power systems through the use of a commercial approach.

The next step in the ECOP program is to design and fabricate, under contract, a 2-kW photovoltaic space power system, using a commercial approach as defined in the earlier study. By conducting this program as a contracted effort, the cost of commercial power systems will be firmly established. The choice of a 2-kW power level allows possible use of the system by free-flyer experiments and allows a system to be developed at low cost which is still large enough to supply information about the cost of future multikilowatt systems. Potential users will be contacted during the design phase, and an appropriate test program for the power system will be evolved through consideration of user needs.

Concurrent with the above program, Lewis is conducting an effort to design, build and flight test a small (less than 100 watt) photovoltaic space power system. This program, called SPEX (Space Power Experiment), will demonstrate the application of industrial hardware for space power systems. Lewis engineers will define the system, select and purchase commercially available components, integrate the system and define and conduct a limited test program.

The SPEX experiment is a low cost, solar array - battery power system. The power system consists of terrestrial solar arrays and an avionics battery and dc to dc power converter. The battery charge scheme is based on the capability of the battery to accept a low rate overcharge for an indefinite time period so no battery charge is required.

All costs will be accounted for in the SPEX program and compared with predictions made by the ECOP studies. The SPEX power system is scheduled to be flight tested on the long-duration experiment facility (LDEF).

TABLE I

Cost of space power systems using space-qualified and commercial components. System operates in LEO, delivers 2 kW average.

<u>Category</u>	<u>Space Qualified</u>	<u>Commercial</u>
Solar Array	\$ 1.5M	\$ 150K
Batteries	180K	5K
Power Processing	360K	10K
Mechanical Systems	225K	75K
Systems Integration and Qualification Testing	400K	150K
	<hr/>	<hr/>
	\$ 2.65M	\$ 390K

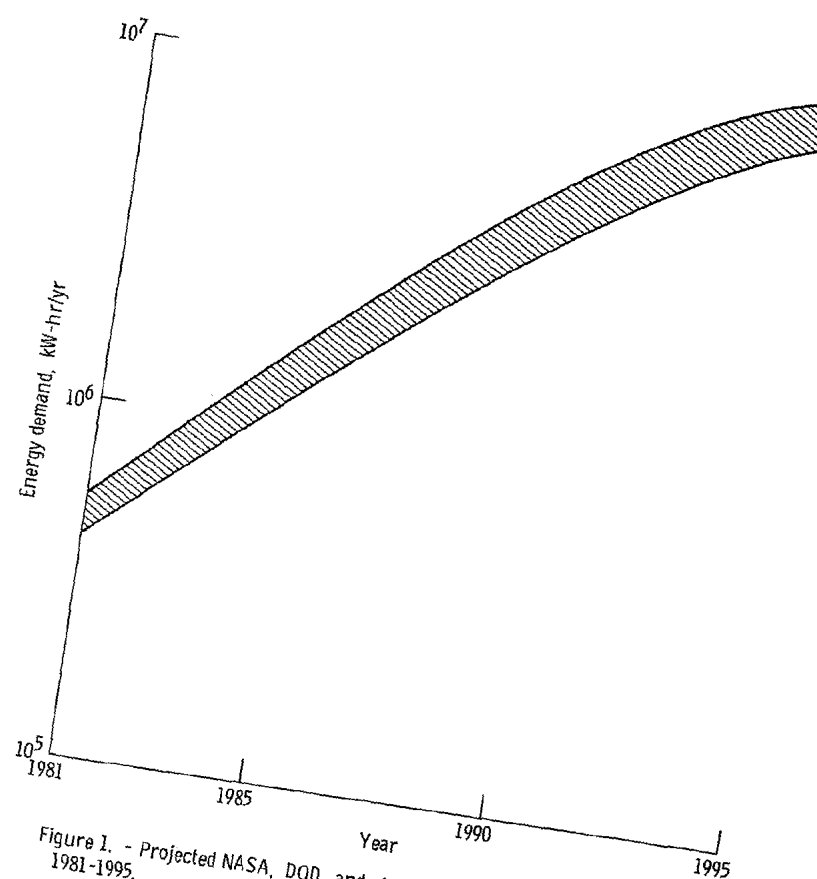


Figure 1. - Projected NASA, DOD, and civil space energy demand for the years 1981-1995.